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# On leading edge erosion at turbine blades due to heavy rain and the application of erosion safe mode control to extend life

*Charlotte Hasager, Jakob I. Bech, Christian Bak*


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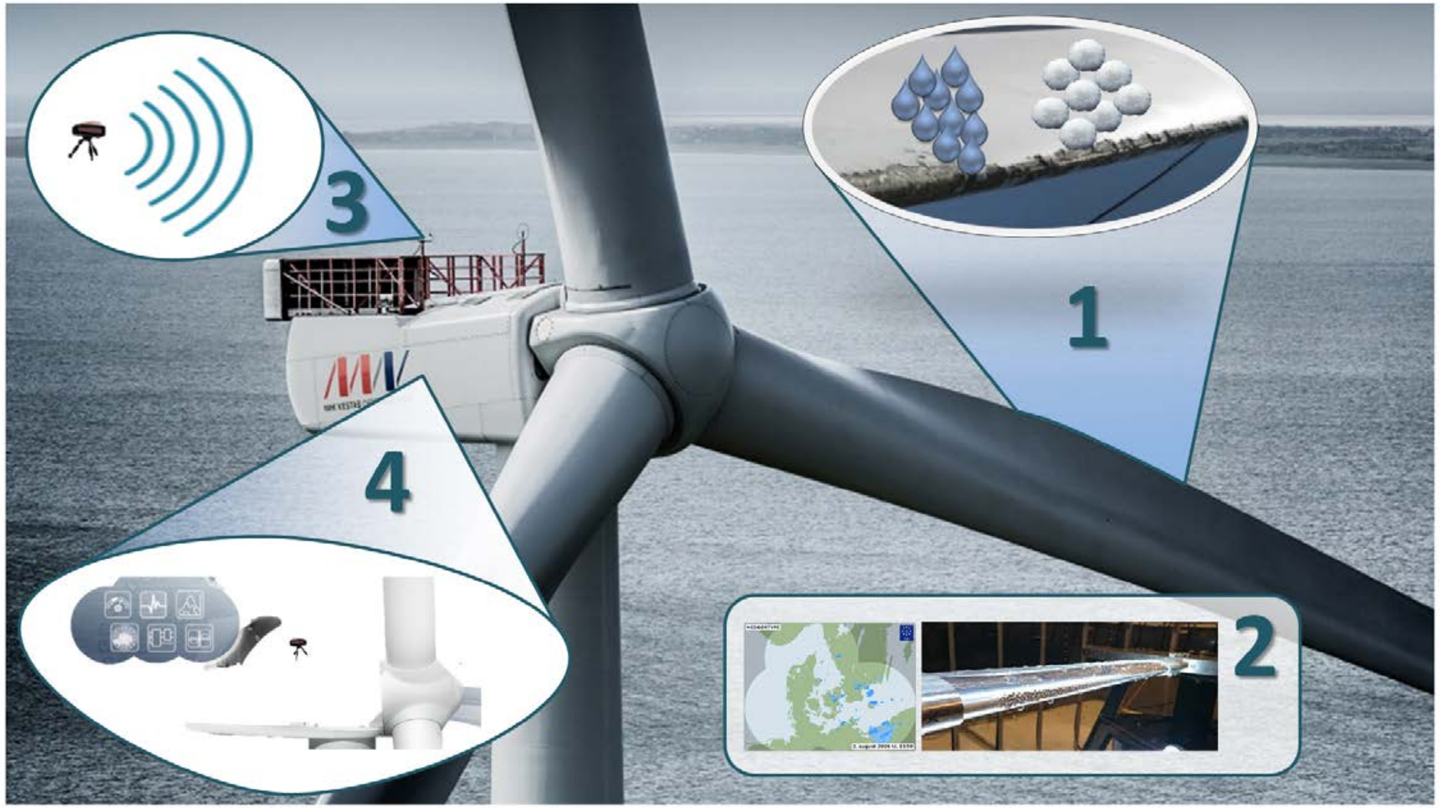
# Motivation

Unforeseen repair cost at several offshore wind farms motivated the research project

# Working hypothesis



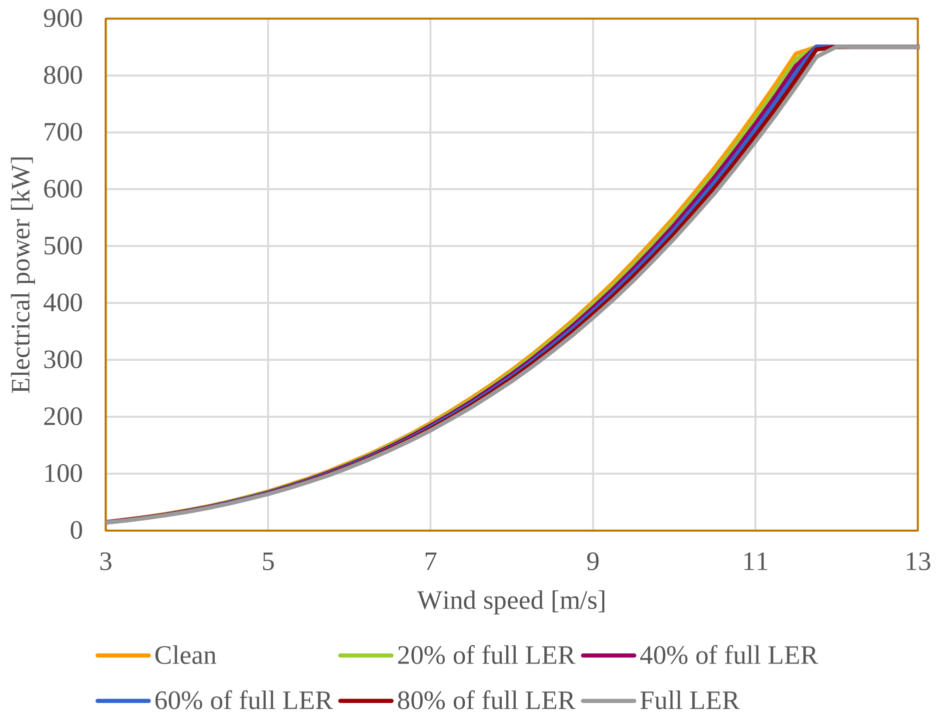

**1.** **Research hypothesis:** Erosion damage is mainly generated during heavy precipitation (big drops of rain or hail), which occurs in a very little fraction of the turbines operation time. By reducing the tip speed of the blades in these few hours a significant extension of the leading edge lifetime can be obtained with negligible loss of production.

**2.** **Methodology:** Define rain and hail erosion classes to quantify leading edge blade in-field and in lab testing. Correlations between rain intensity, droplet size, impact speed, materials properties, etc. will be established.

**3.** **Measurement Device:** Low-cost prototype for precipitation measurement on site and real time warning device enabling modern control of wind turbines.

**4.** **Erosion safe mode:** A safe mode control based on the erosion classes to control the wind turbine, reducing the tip speed under severe conditions – preventing aerodynamic degradation and reducing maintenance costs.

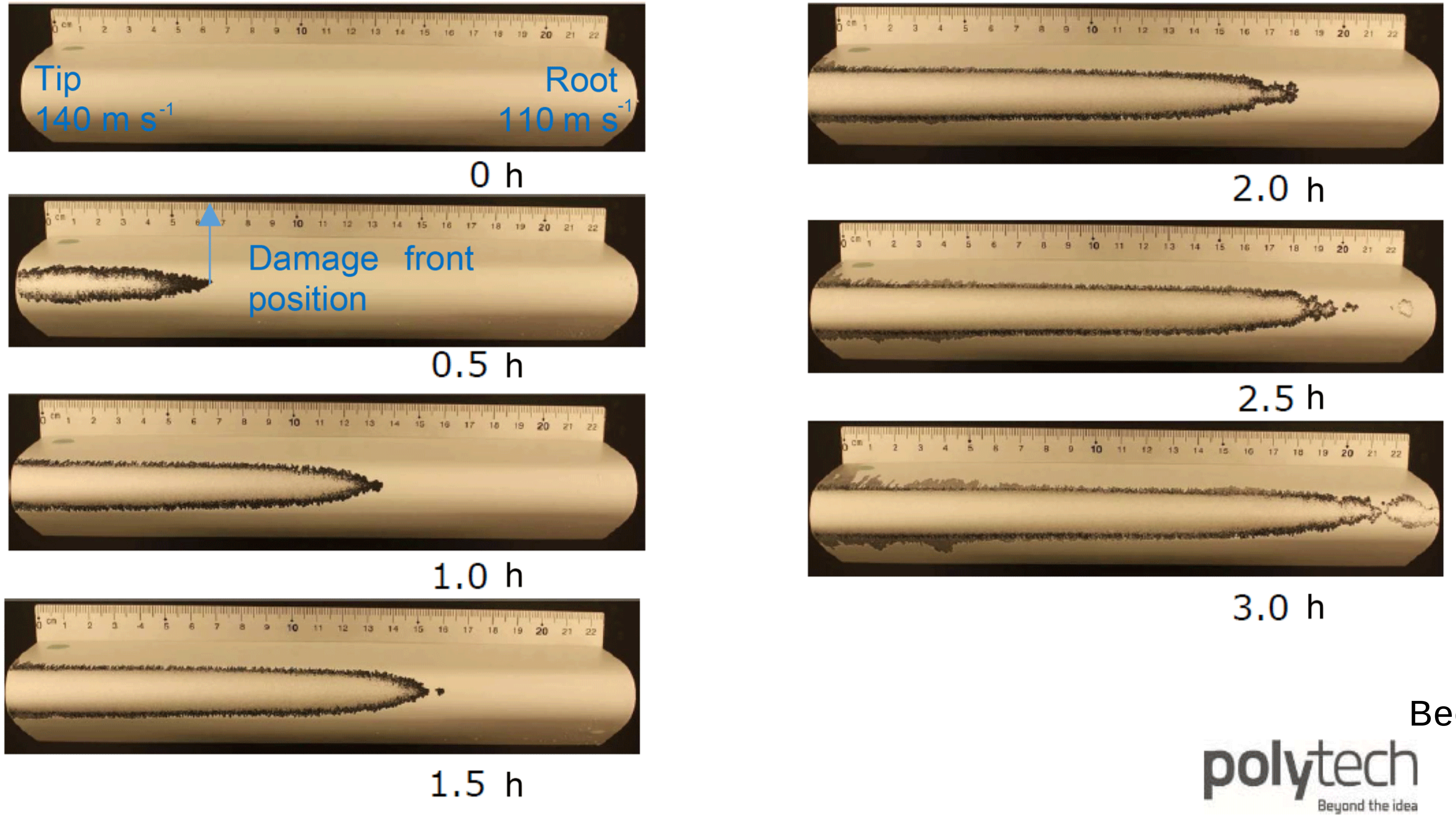
# Simulated power curves for the Vestas V52 for different leading edge roughness levels




Bech *et al.* 2018, WES

LER is leading edge roughness. Roughness levels increase for eroded blade.

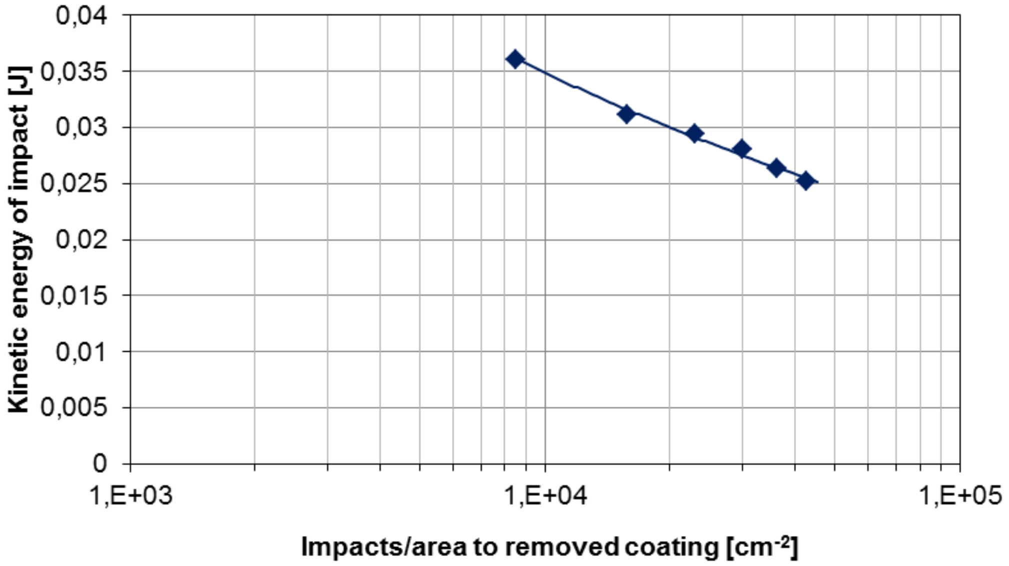
# Rain erosion test example




Bech *et al.* 2018, WES

# Rain erosion test data plotted as a Wöhler curve

Impacts per unit area to failure as function of the kinetic energy for each impact

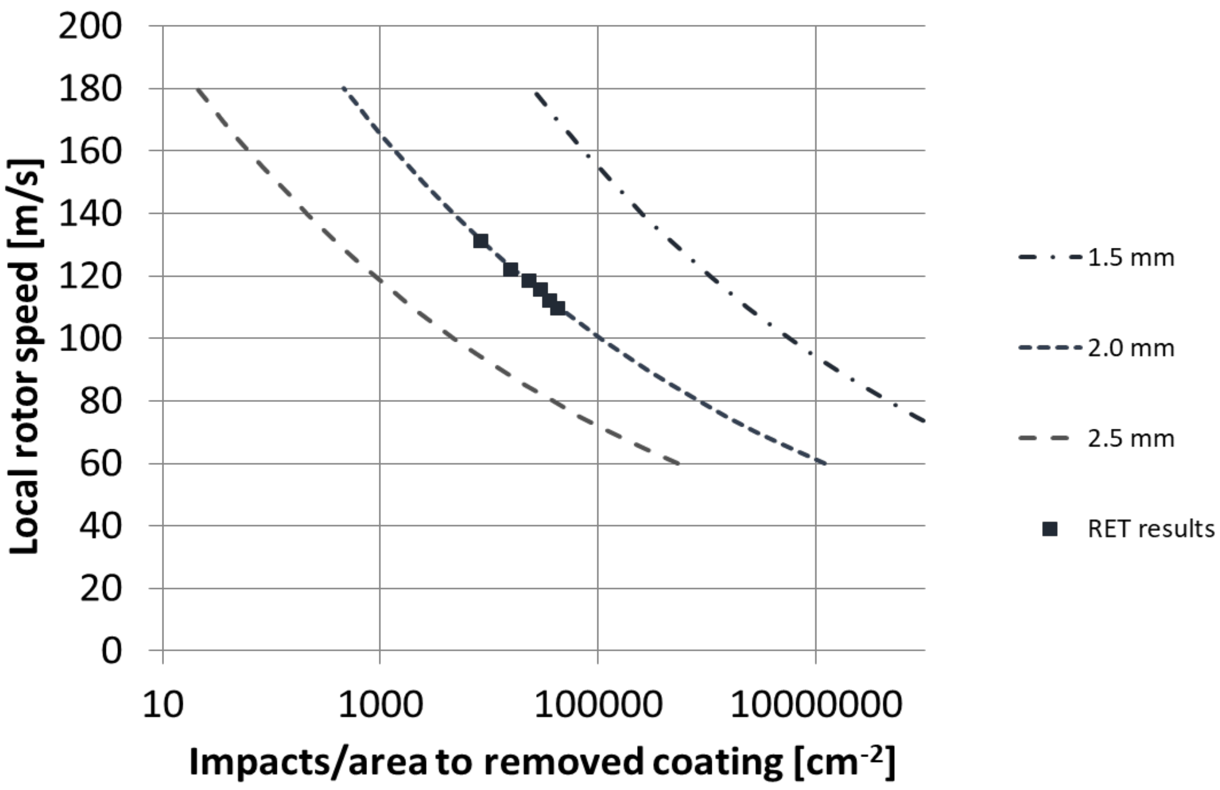



$$E_k = \frac{1}{12}\rho\pi D^3 v_t^2 \text{ [J]}$$

*D* is drop size
$v_t$ is blade speed

Bech *et al.* 2018, WES

# Wöhler curves for droplet diameters of 1.5, 2.0 and 2.5 mm




RET is Rain Erosion Test

Bech *et al.* 2018, WES

# Extending lifetime

# Assumptions:

## Wind turbine

Vestas V52 850 kW pitch regulated variable speed and modified rotation speed to make it consistent with larger turbines.

## Rain climate

The temperate maritime climate of occurences of rain intensity is taken from Jones and Sims, 1978.

## Wind climate

Weibull A

- 7 m/s
- 8 m/s
- 9 m/s

Bech *et al.* 2018, WES

# Control strategies

- Control strategy 1 No reduction (90 m/s)
- Control strategy 2 Reduction ”light” 80 m/s and 70 m/s
- Control strategy 3
- Control strategy 4
- Control strategy 5 Reduction ”severe” 55m/s, 65m/s and 70m/s
- Control strategy 6 Idealized

Bech *et al.* 2018, WES

# Life time of the blade leading edge with no reduction of the tip speed.
# Control strategy 1

| Rain intensity [mm/hr] | Droplet size [mm] | Percent of time [%] | Hours pr year [hrs/year] | Blade tip speed [m/s] | Hours to failure [hrs] | Fraction of life spent pr year [%] |
|---|---|---|---|---|---|---|
| 20 | 2.5 | 0.02 | 1.8 | 90 | 3.5 | 51 |
| 10 | 2.0 | 0.1 | 8.8 | 90 | 79 | 11 |
| 5 | 1.5 | 1 | 88 | 90 | 3606 | 2.4 |
| 2 | 1.0 | 3 | 263 | 90 | 745710 | 0.0 |
| 1 | 0.5 | 5 | 438 | 90 | 2830197826 | 0.0 |
| | | | | Sum of fractions [%]: | | 64 |
| | | | | Expected life [years]: | | 1.6 |

Bech *et al.* 2018, WES

# Life time of the blade leading edge with reduction of the tip speed to 70m/s and 80m/s. Control strategy 2

| Rain intensity [mm/hr] | Droplet size [mm] | Percent of time [%] | Hours pr year [hrs/year] | Blade tip speed [m/s] | Hours to failure [hrs] | Fraction of life spent pr year [%] |
|---|---|---|---|---|---|---|
| 20 | 2.5 | 0.02 | 1.8 | 70 | 46 | 3.8 |
| 10 | 2.0 | 0.1 | 8.8 | 80 | 263 | 3.3 |
| 5 | 1.5 | 1 | 88 | 90 | 3606 | 2.4 |
| 2 | 1.0 | 3 | 263 | 90 | 745710 | 0.0 |
| 1 | 0.5 | 5 | 438 | 90 | 2830197826 | 0.0 |
| | | | | Sum of fractions [%]: | | 9.6 |
| | | | | Expected life [years]: | | 10.4 |

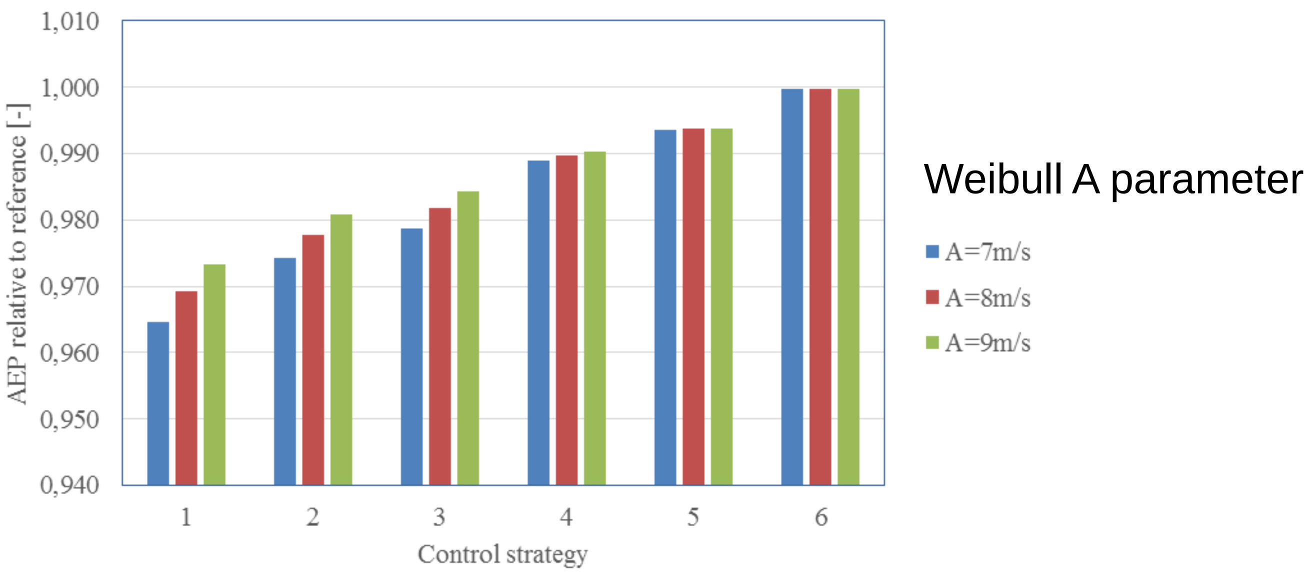
Bech *et al.* 2018, WES

# Life time of the blade leading edge with reduction of the tip speed to 55m/s, 65m/s and 70m/s.
# Control strategy 5

| Rain intensity [mm/hr] | Droplet size [mm] | Percent of time [%] | Hours pr year [hrs/year] | Blade tip speed [m/s] | Hours to failure [hrs] | Fraction of life spent pr year [%] |
|---|---|---|---|---|---|---|
| 20 | 2.5 | 0.02 | 1.8 | 55 | 541 | 0.3 |
| 10 | 2.0 | 0.1 | 8.8 | 65 | 2215 | 0.4 |
| 5 | 1.5 | 1 | 88 | 70 | 47514 | 0.2 |
| 2 | 1.0 | 3 | 263 | 90 | 745710 | 0.0 |
| 1 | 0.5 | 5 | 438 | 90 | 2830197826 | 0.0 |
| | | | | Sum of fractions [%]: | | 0.9 |
| | | | | Expected life [years]: | | 107 |

Bech *et al.* 2018, WES

# AEP relative to AEP with no erosion




Bech *et al.* 2018, WES

# Cost of operation and maintenance

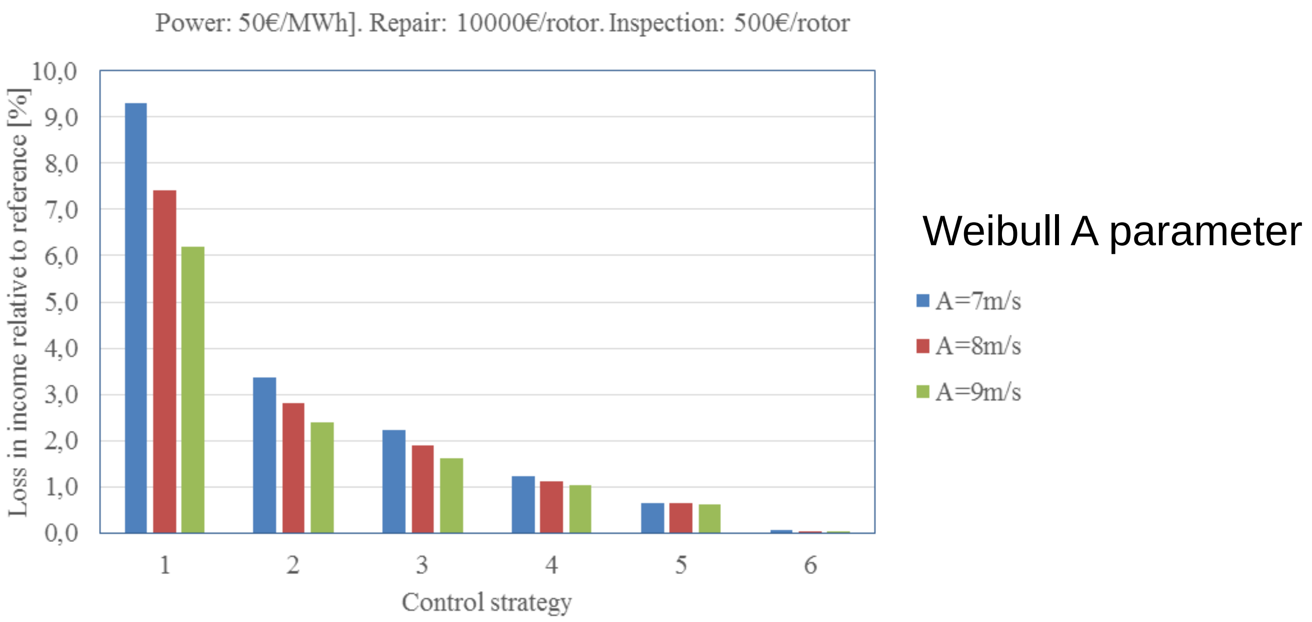
- Energy price:
  - $\boxed{\text{50 €/MWh}}$
  - 250 €/MWh
- Inspection cost:
  - $\boxed{\text{500 €/rotor}}$
  - 1500 €/rotor
- Repair cost
  - $\boxed{\text{10000 €/rotor}}$
  - 20000 €/rotor

Stand still of 1 day inspected

Stand still of 2 days repaired

Bech *et al.* 2018, WES

# Loss of income due to erosion, inspection and repair




Bech *et al.* 2018, WES

# In what geography is leading edge erosion a challenge?

# Rainfall erosivity (for soils)

# Rainfall erosivity (for wind turbine blades?)

Rainfall erosivity  for soils is modelled as a function of the kinetic energy of rain, the maximum intensity of rainfall, the cumulative rainfall, the soil properties and the slopes of terrain. The map on rainfall erosivity in Europe at 500 m spatial resolution assessed by European Soil Data Centre (Panagos et al., 2015).

A map for wind turbine blades is in preparation in the EROSION research project.

# Conclusions

A framework for prediction and a mitigation strategy for leading edge erosion was presented.

The model takes into account the entire value chain: leading edge test data, actual on site precipitation, erosion rate, loss of production due to erosion, operation and maintenance.

The lost energy production due to occasional tip speed reduction is marginal in proportion to the alternative of lost production due to eroded blades.

Thus, the cost – benefit balance of erosion control looks very promising and shows a great potential for reducing the loss of produced energy due to erosion and the cost of operation and maintenance.

To accomplish erosion control there is a need for more knowledge on the correlation between precipitation and erosion for different leading edge structures and materials, and for development of methods and equipment for on-site now casting of precipitation.

# Reading:

Wind Energ. Sci., 3, 729–748, 2018
https://doi.org/10.5194/wes-3-729-2018


eawe european academy of wind energy

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## Extending the life of wind turbine blade leading edges by reducing the tip speed during extreme precipitation events

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www.rain-erosion.dk